DOCUMENTO ORIGINAL EN MAL ESTADO

A STRUCTURAL VIEW OF CASUALTY ESTIMATION

William T. Holmes
Vice-President
Rutherford & Chekene

Attached to this paper as an Appendix is Section 6, "Damage Estimates," of the study entitled "Seismic Retrofitting Alternatives for San Francisco's Unreinforced Masonry Buildings. Estimates of Construction Cost and Seismic Damage." In order to compare retrofit alternatives, it was necessary to estimate damage for each alternative as well as casualties. Since a database of information about the 2,000 unreinforced masonry (URM) buildings was available, damage was estimated by computer on an individual building-by-building basis. Often, this may not be possible or feasible, but the parameters needed to estimated casualties would be the same in any case

Most of the parameters themselves are highly variable and cannot be predicted with certainty for any individual building. However, as more buildings are included in an inventory the values selected will become more representative. It has been estimated that, considering the process to estimate seismic damage, the coefficient of variance (considering random variation, not systematic errors) for a single building may be between .5 and 1.0, but with each 100 buildings added to the inventory, this coefficient will reduce by a factor of 10. So, if a relatively large number of buildings are considered, damage can be satisfactorily estimated, assuming the values selected for the parameters are accurate to begin with.

In order to calculate estimates of casualties that consider as many effective characteristics of the situation as possible, the parameters listed in Table 1 are needed. The major headings can be considered minimum data and the sub-items are important refinements.

Table 1: Parameters of Casualty Estimation

Building Definition

- Structural System
- Special Characteristics
- Street Exposure

Exposure

- Occupancy within building
- Occupancy exposed adjacent to building
- Variation by time of day

Shaking Intensity

- Site location
- Site soils conditions

The variability of the parameters can easily be demonstrated with a few examples.

Table 2 estimates the annual risk of fatality per square foot for several building types at several Bay Area locations. These figures were calculated using ATC 13 damage relationship and fatality rates. The top figures are calculated using common occupancies and are therefore a pure measure of seismic risk at the site. The lower figures are adjusted for more occupancies. The large difference between URM and nonductile concrete is surprising and possibly not justified considering the historical data shown in Table 3.

Expected variations in shaking intensities due to local soils conditions can be seen in Figure 4, taken from Idriss (1990).

The importance of and variation in exposures in and around buildings and for different times of day can be seen in Tables 5, 6 and 7, which were obtained as part of URM studies. These figures are limited to only URM building exposures, but are probably representative of the global variations in these parameters.

TABLE 2

COMPARISON OF RELATIVE ANNUAL RISK OF FATALITY PER SQUARE FOOT OF VARIOUS BUILDING TYPES IN VARIOUS CITIES

Building Type	Occupancy Rate/1000 sf	San Francisco	Oakland Downtown	Oakland Near Fault	Livermore	San Rafael
URM	1.0	7.0	16.0	24.0	5.0	3.0
Nonductile concrete	1.0	1.2	2.0	3.4	1.0	0.6
Tilt-up	1.0	0.9	1.5	2.0	0.8	0.4
URM	2.1	15.0	34.0	52.0	12.0	7.0
Nonductile concrete	2.3	2.8	5.4	8.0	2.5	1.4
Tilt-up	1.0	0.9	1.4	2.0	0.8	0.4

- Actual x 10^9
- Damage, Fatality rates from ATC 13

TABLE 3

FATALITIES FROM EARTHQUAKES IN WESTERN U.S.

EVENT		FATALITIES	
Location	Year	Total	Estimated from URM Bearing Wall
Fort Tejon	1857	1	1
Hayward	1868	30	15
Owens Valley	1872	27	13
San Francisco	1906	700-800 (+)	200-500
Santa Barbara	1925	12-14	< 10
Long Beach	1933	86-100	50-80
Imperial Valley	1940	8	4-8
Puget Sound	1949	8	4-8
Kern County	1952	14	5-10
Alaska	1964	125	< 5
Puget Sound	1965	3	1-3
San Fernando	1971	58	1
Coalinga	1983	11	1
Idaho	1983	2	2
Whittier	1987	3	0
Loma Prieta	1989	62	8
Totals		1,202	492 (41%)
Since 1950		268	26 (10%)

Occupancy of one 100,000 sf nonductile
concrete frame office or residence 300

TABLE 4

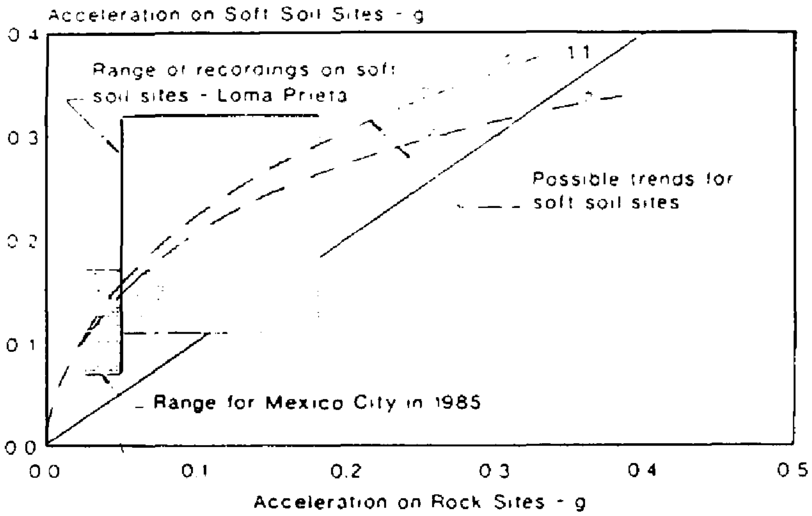


Fig. 3 OBSERVED VARIATIONS OF PEAK HORIZONTAL ACCELERATIONS ON SOFT SOIL SITES IN COMPARISON TO ROCK SITES

SOURCE: Idriss, 1990

TABLE 5

VARIATION OF POPULATION EXPOSED TO UMB HAZARDS IN SAN FRANCISCO

	3 am	3 pm	5:30 pm
In Building	63,000	127,000	84,000
On Street	214	7,500	18,000

TABLE 6

DAY TIME EXPOSURE - VARIOUS CITIES

	San Francisco	Ventura	Santa Monica
Population	700,000	92,000	64,000
In Building	127,000	4,700	9,500
Relative	1:5	1:20	1:7
On Street	7,500	120	470
Relative	1:90	1:800	1:140

TABLE 7

ANNUAL RISK OF FATALITIES FROM URMs - VARIOUS CITIES

	San Francisco	Ventura	Santa Monica
Total Expected Fatalities Per Year	12.6	0.18	0.27
Population	700,000	92,000	64,000
Annual Risk per 100,000 population	1.8	0.2	0.42
Area of URM, SF	36,209,808	752,508	1,137,500
Annual Risk per 100,000 SF URM	0.033	0.024	0.024

APPENDIX

Extracts from Section 6 of
"Seismic Retrofitting Alternatives for San Francisco's Unreinforced Masonry Buildings:
Estimates of Construction Cost and Seismic Damage"
(Rutherford & Chekene, 1990)

6: DAMAGE ESTIMATES

6.1 OVERVIEW OF PROCEDURE

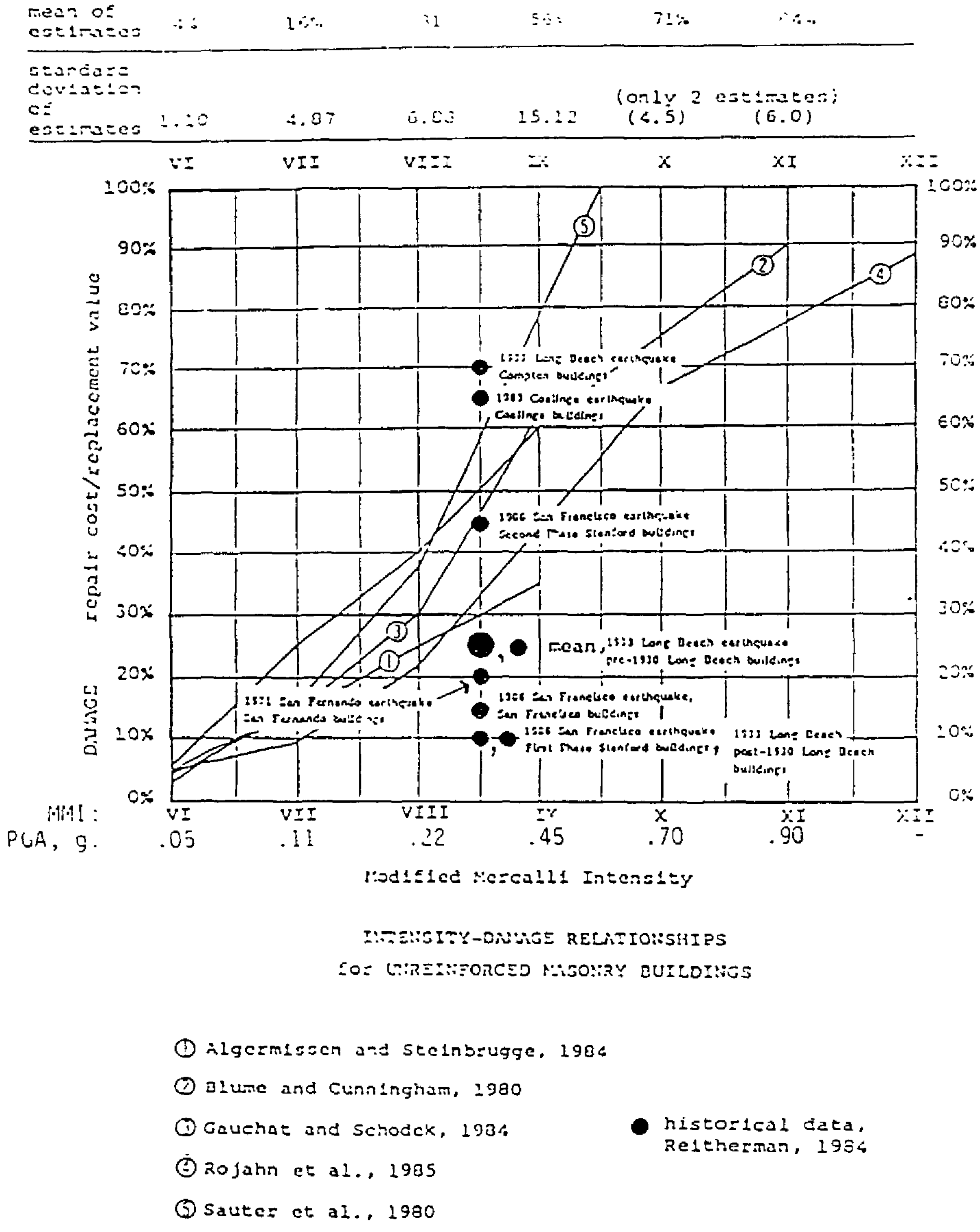
Damage has been estimated using a computerized Seismic Risk Model (SRM) that considers shaking intensity at each site and damage characteristics of each building. Local shaking intensity is estimated using calculated fault distances, standard attenuation relationships, and site soil conditions. Peak Ground Acceleration (PGA) is initially calculated and then converted to projected Modified Mercalli Intensities (MMI) PGA and MMI are used concurrently to identify shaking intensities for estimation of damage. Several Intensity-Damage relationships as well as additional analysis of UMBs were previously prepared by Reitherman and are shown in Figure 6.1 to illustrate this concept The raw PGA equivalent of each Modified Mercalli Intensity is also shown on Figure 6 1 The effective PGA normally used for code mapping and dynamic analysis is generally taken as three quarters of these values Descriptions of the Modified Mercalli Intensity Scale are common in the literature and will not be repeated here. Given the location and characteristics of each fault source, local shaking intensities can be estimated not only for specific events, but also on a probabilistic basis for all events. Both the estimation of intensities for any event and the expected damage can have large variations. For this study, both have been taken to be average values.

Building damageability is estimated considering its prototypical characteristics and other specific attributes contained in the database. Once the model is set up, damage can easily be estimated for a specific event, or the expected accumulated damage over any period of time can be estimated by combining the probabilities of occurrence of each shaking intensity with the smooth curve relating intensity and damage. In this study, probabilistic results have been reported on an annual expected loss basis This is not to say that such losses are expected annually, but rather that losses would approximately average the annual expected loss over an extended period of time Since a major earthquake could occur at any time and skew short-term accumulated losses, annual loss results can be misleading if interpreted literally. However, when various alternative actions are to be analyzed, use of probable annualized results is the most valid method of comparison

A detailed description of SRM is contained in Appendix 4

For this project, relationships were developed between building damage and casualties as well as building damage and loss of building use Casualties were estimated considering both building occupants and sidewalk pedestrians. The population thus at risk varies a great deal with time of day An algorithm for estimating loss of building use was also developed, based primarily on experiences in Loma Prieta earthquake, which considers structural evaluation delays, reasonable damage repair rates, and critical loss levels, where demolition is likely

As discussed in Section 5. Synthesis of Professional Opinion on Retrofits, there is little hard data on building performance and its relationship to loss parameters Many assumptions were necessary to generate the detailed damage, casualty, and downtime data contained herein. Numerical coefficients that were required were based upon available data and engineering judgment. Surprisingly, based upon several test runs, the overall model is not very sensitive to adjustments of most individual assumptions. Minor adjustments to some numerical coefficients were made, however, based on initial output covering the most well studied and documented scenarios the recent Loma Prieta earthquake and the Richter Magnitude 8 3 on the San Andreas



source· Robert Reitherman

Figure 6.1: Example Damage-Intensity Relationships

The assumptions used in the loss estimates are detailed in Sections 6.2 through 6.5. Results are given in Section 6.6. A large volume of data has been generated, and, for efficiency and completeness, is presented in 32 tables directly as output from the computer calculations. Variables output as percentages or numbers of people were rounded to tenths to reduce apparent round-off errors that would result if rounded further. Variables output as dollars or square feet are larger numbers and were rounded as whole numbers, for similar reasons. This rough output format results in outputs of fractions of individuals and apparent seven-place accuracy of larger numbers. It should be recognized that neither is realistic but is merely a result of the chosen output format.

6.2 DAMAGE - INTENSITY RELATIONSHIPS

Relationships between damage (measured as a percentage of replacement costs) and shaking intensity have been developed for each prototype under each strengthening condition. The damage estimated is considered to be average damage when measured over many buildings. Although a damage figure was calculated for each building considering its own attributes, it is not to be considered the actual damage expected to that specific building but a weighting factor that will affect the overall average. Actual individual damage to each building will vary widely and is dependent on detail beyond the available database and calculation methodology.

Consideration of 15 prototypes under 4 strengthening conditions implies 60 damage curves. It is clear that no such fine tuning of damage estimates is reasonable or possible. However, it is possible to judgmentally rank damageability of prototypes, or at least to put them in groups of approximate equal damageability. This type of grouping of prototypes can be done for the strengthened condition as well as unstrengthened. Intuitively, the more strengthening is done, the less variable will be the damage, as retrofit requirements are intended to produce a constant risk level across buildings.

Review of the prototypes and their characteristic damage patterns indicated that five levels of damageability were reasonable for the unstrengthened case, three for Retrofit Alternative 1, and two each for Retrofit Alternatives 2 and 3.

Starting with the damage relationships from ATC-13 (ATC, 1985) for URMs, values for existing unstrengthened San Francisco buildings were estimated considering prototypical characteristics. These damage relationships were consistently below ATC-13 for the following reasons:

- An early simplifying assumption of this study was that all non-conforming parapets were assumed to be retrofitted. Included in the parapet retrofit work were roof ties and anchoring of roof-line falling hazards. This work will clearly reduce the damage from 'average' URM levels. For one-story buildings, this work would be a significant part of a total retrofit and would therefore cause a relatively large reduction in damage.

- The typical San Francisco UMB is felt to be better than the UMB normally envisioned as average, not only due to parapet retrofits, but also due to fairly consistent use of government anchors, generally better quality mortar, and minor local seismic improvements often incorporated in remodels.

- ATC-13 relationships were developed to apply to all buildings under all conditions. No individual characteristics were presented for use in modifying the values of the

Table 6.2-1: Damage as a Proportion of Replacement Value for Various Conditions

PGA, g	0.05	0.11	0.22	0.45	0.7	0.9	--
MMI	VI	VII	VIII	IX	X	XI	XII
Unstrengthened							
U-1	0.01	0.05	0.14	0.27	0.39	0.52	0.65
U-2	0.01	0.06	0.18	0.32	0.43	0.58	0.7
U-3	0.01	0.07	0.22	0.37	0.5	0.67	0.8
U-4	0.01	0.08	0.26	0.42	0.55	0.7	0.8
U-5	0.01	0.1	0.28	0.47	0.6	0.73	0.8
Alt. 1 Strength							
1-1	0.005	0.03	0.11	0.25	0.38	0.51	0.65
1-2	0.005	0.04	0.15	0.29	0.4	0.53	0.67
1-3	0.005	0.05	0.21	0.35	0.46	0.59	0.75
Alt. 2 Strength							
2-1	0.005	0.02	0.1	0.18	0.28	0.44	0.6
2-2	0.005	0.03	0.12	0.23	0.34	0.47	0.6
Alt. 3 Strength							
3-1	0.005	0.01	0.06	0.15	0.24	0.39	0.55
3-2	0.005	0.02	0.08	0.17	0.28	0.41	0.55
ATC-13							
URM	0.047	0.107	0.291	0.491	0.701	0.823	0.902
RFM	0.003	0.029	0.06	0.135	0.232	0.419	0.523

damage curves. In this study, baseline damage curves were selected, and then individual building attributes were used as damage modifiers (see Section 6.3). Since these modifiers generally tend to increase the damage from the values on the baseline curves, the baseline values were purposefully lowered below what they would have been without the damage modifiers.

- Loma Prieta damage as well as several other data points established by Reitherman (Figure 6.1) indicate that traditional average damage curves may be high.

The five final damage relationships for unstrengthened buildings are shown in Table 6.2-1 labeled as U-1 thru U-5. ATC-13 values for UMBs are also shown in Table 6.2-1 as "URM-ATC-13". Specific values for U1-U5 were established considering the following:

- The values and "shapes" of damage curves developed by others both for URMs and other type buildings.
- UMB damage types as described in Section 3.2 and the shaking intensities likely to produce each one.
- Characteristics of nonstructural elements, particularly partitions, and at what shaking intensities damage is likely.
- "Damage" in these relationships is average to represent many buildings and must recognize wide variations in shaking characteristics and building resistance.

Next, damage relationships were estimated for Retrofit Alternative 3 which was considered to produce the least damage. Retrofit Alternative 3 was deduced to have the best performance for the following reasons:

- Although tension tie design requirements are less stringent than Alternative 2, the allowable loads are also lower, which produces very similar tie requirements.
- The equivalent out-of-plane bending requirements are stricter than Alternative 2.
- The requirements generally produce a much stiffer building that will better protect the UMB walls from damage, particularly at low to moderate shaking intensities.
- Smaller diaphragm deflections and no reliance on "nonstructural" walls will result in less partition damage.
- The requirements are similar to conventional design for new buildings and can be well defined in regulations, creating less variation in engineering interpretation and construction execution.

Damage variation between prototypes was considered to be small and only two sets of damage relationships were created, and are shown as 3-1 and 3-2 in Table 6.2-1. Damage expected from this Alternative is assumed to be considerably greater than that in recently designed buildings, but only slightly greater than that expected in "poor" shear wall type buildings designed in accordance with codes previous to the 1976 Uniform Building Code (UBC). The ATC-13 damage relationship for reinforced masonry buildings, which includes pre- and post-seismic code buildings, was selected as a lower bound. These damage values are shown in Table 6.2-1 as "RFM-ATC-13".

Damage relationships for Alternative 1 and 2 were estimated in a similar manner and generally presumed to fall between Unstrengthened and Alternative 3. Because a wider variation in damage patterns is expected from Alternative 1 due to its incomplete mitigation of deficiencies, three relationships were utilized as shown as 1-1, 1-2, 1-3 in Table 6.2-1. Two relationships with a relatively large variation at intensities IX and X were used for Alternative 2, primarily to account for expected cracking in exterior walls with openings, these are labeled 2-1 and 2-2 in Table 6.2-1

Once the various characteristic damage relationships were established, the appropriate relationship was assigned to each prototype for the unstrengthened case and each strengthening condition, considering the particular characteristics of the prototype, creating a set of four damage "curves". These assignments are shown in Table 6.2-2. Initial damage relationships were entered into SRM and results calculated for several conditions, including Magnitude 8.3 San Andreas and Loma Prieta-type events. The total damages so calculated were judged reasonable; damage from Loma Prieta was estimated at about 5.1%, versus our initial survey results of 3.85% (see Section 7); total damage for the 8.3 San Andreas event including all site conditions and modifiers was estimated at 42%.

Table 6.2-2: Damage Relationship Key by Prototype and Condition

	Damage Relationship Number for Each Condition			
Prototype	Unstrengthened	Alternative #1	Alternative #2	Alternative #3
A	U-1	1-1	2-1	3-1
B	U-2	1-1	2-1	3-1
C	U-3	1-2	2-2	3-1
D	U-4	1-3	2-2	3-2
E	U-4	1-1	2-1	3-1
F	U-5	1-2	2-1	3-1
G	U-2	1-2	2-1	3-1
H	U-3	1-3	2-1	3-1
I	U-4	1-3	2-2	3-2
J	U-4	1-3	2-2	3-2
K	U-1	1-1	2-1	3-1
L	U-2	1-2	2-2	3-1
M	U-2	1-2	2-2	3-2
N	U-3	1-2	2-2	3-2
O	U-5	1-3	2-2	3-2

The set of four damage relationships for each prototype was then reviewed as individual groups for consistency and reasonableness. This check resulted in adjustments in most data points. These adjustments were, in general, minor, with few exceeding changes of more than 10%. Several different sets of damage relationships were used in SRM during these adjustments, and the resulting damages proved surprisingly insensitive. It was concluded that this apparent insensitivity to the total exact values of the damage relationships was due to the averaging effect of many prototypical and shaking intensity conditions represented in each calculation, and to the modifiers to average damage relationships that were used on a building-by-building basis to reflect the specific characteristics of San Francisco sites and UMBs (see Section 6.3).

Unfortunately, considering the inadequacy of available data, any damage estimation methodology will be most heavily influenced by judgmental parameters. In these calculations, however, the use of several different damage points as appropriate for site specific shaking intensities, and the use of damage modifiers to better represent actual conditions, break down judgmental factors into specific subject areas with fairly well established trends. The final results are a measure of a complex combination of these trends and should represent a reasonable estimate of the actual damage conditions, particularly for comparison of alternatives or comparison of damage under different scenarios.

6.3 SITE-SPECIFIC MODIFICATION TO DAMAGE-INTENSITY RELATIONSHIPS

Part of the strength of the calculation methodology used in this study is the ability to consider specific attributes of each site and building and thereby weight average results to better represent the actual San Francisco conditions. Many attributes were considered for use, but little data exists that can be used to rationalize quantitative effects on damage. The modifications used, and described below, are not believed to be qualitatively controversial. The sizes of modifications used are largely undocumented and judgmental.

6.3.1 SITE SOILS MODIFICATION TO SHAKING INTENSITY

The most obvious site-specific characteristic to account for is site soils. The amplification of shaking due to soils conditions is well documented and was again demonstrated in the Loma Prieta Earthquake. The soils data available in the San Francisco UMB database was an ABAG Geologic Classification of nine categories (ABAG, 1987). Seismic risk analysis work at Stanford University has suggested an increase in one step of MMI for soft soils and a decrease in one intensity step of MMI for firm soils. This modification was used as shown in Table 6.3-1:

TABLE 6.3-1: Soil Modifications to Shaking Intensity

ABAG Classification	Change in MMI Intensity
8,9	+1
4,5,6,7	0
1,2,3	-1

Potential added losses due to liquefaction were not considered in this study. Liquefaction potential is difficult and expensive to mitigate locally under an existing building, and no special requirements are currently planned for inclusion in any of the UMB ordinance options. Since most UMB strengthening methods have limited effectiveness against liquefaction damage, these would tend to cancel out when comparing alternatives.

6.3.2 MODIFICATIONS TO AVERAGE DAMAGE CONSIDERING BUILDING ATTRIBUTES

Modifications were made in average prototypical damage relationships considering two attributes: story height and adjacencies.

The database of damage from the Loma Prieta Earthquake showed a clear pattern of increased damage in buildings with larger story heights (see Section 7). In fact, other than soils, this was the only pattern that emerged from initial analysis of that database. Therefore, for buildings with average story heights equal to or greater than 16 feet, damage was increased equivalent to an increase in MMI of .25 intensity steps. Presuming that increased damage was primarily due to out-of-plane failures, and that all three Retrofit Alternatives would mitigate this problem, this modification was only done in calculations for the unstrengthened condition.

Detailed adjacency information was collected as a part of the supplementary data collection effort at the start of this study (see Appendix 1). Using these data points, it is possible to determine whether spaces adjacent to a given building are open or occupied by a building, whether the building is URM, and whether it is taller or shorter than the building under consideration.

Many instances of pounding-type damage have been recorded in earthquakes, particularly when adjacent buildings are shorter and create an abrupt change in stiffness. A corollary to this condition is the case of a building restrained by equal or taller buildings on both sides. Although minor pounding damage may occur, the damage from lateral response is generally smaller, due to interaction with the neighboring buildings. Damage has also often been caused in a building from falling debris from adjacent, taller buildings, normally UMBs. Another common observation, particularly in urban, compacted blocks, is increased damage to corner buildings, probably caused both by their position in the block and also by a lack of symmetry in exterior walls created by the two streetfront walls having many openings. These conditions were used to modify average damage equivalent to MMI intensity steps as shown in Table 6.3-2. Similar to the story height modification, higher adjacent UMBs were assumed to increase damage only in the unstrengthened condition.

Table 6.3-2: Damage (Intensity) Modifications due to Adjacencies

Condition	Result	Unstrengthened	Strengthened
One side higher - UMB	Falling debris	+.25	0
Two sides higher - UMB	Falling debris	+.5	0
Two sides lower - any building	Abrupt change in stiffness	+.25	+.25
Two sides equal or higher - non UMB	Restraint	-.25	-.25
Two sides street - Two opposite sides - any building	Corner building	+.25	+.25

6.3.3 OTHER ATTRIBUTES

The database contained many other attributes that could affect damage, such as number of stories, soft story, plan configuration, number of reentrant corners, age, and diaphragm ratio. They were not used as damage modifiers for a variety of reasons. Soft story, for example, was not used because the database entries (see Appendix 1) were considered inconsistent and unreliable. In non-rectangular configurations, the fact that all exterior walls in UMBs are resisting elements and the preponderance of flexible diaphragms may compensate for the irregularities normally considered to increase damage. Inconsistent, insignificant or poorly documented cause and effect were also considered when examining the usefulness of these attributes for damage modification consistent with the overall methodology of this study.

6.4 DAMAGE-CASUALTY RELATIONSHIPS

Casualty rates for earthquakes have generally been estimated for the entire population at risk. Analysis and use of actual data must be on that basis because casualty data is not available per building type or on the basis of actual number of occupants per building. The most recent assessment of rates more closely related to individual buildings was presented in ATC-13 (ATC, 1985) and are shown in Table 6.4-1. Rates had previously been proposed by individual building types for a major earthquake by the California Seismic Safety Commission for the purpose of evaluating California owned buildings (CSSC, 1979), and are shown in Table 6.4-2.

Table 6.4-1: ATC-13 Fatality Rates for All Buildings Except Light Steel and Wood Frame

Central Damage Factor (%) :	0	.5	5	20	45	80	100
Fatality Rate :	0	$1/10^{6}$	$1/10^{5}$	$1/10^{4}$	$1/10^{3}$	$1/10^{2}$	1/5

Table 6.4-2: Fatality Rates for Unspecified Large Earthquake Suggested for UMBs by California Seismic Safety Commission

Condition :	Unstrengthened	Attainable by Strengthening
Fatality Rate :	4,000/10,000 [2/5]*	15/10,000 [15/10^{4}]*

*For comparison to ATC 13.

The rates used by California are clearly to be applied to the number of building occupants: although not specifically so stated, the ATC rates also seem to be intended to be applied to the number of building occupants.

Considering that the primary failure mode of UMBs is the outward collapse of walls or parts of walls, the exposure for life safety hazard is probably not directly proportional to occupancy of the building. This is particularly true in San Francisco, where there has been great concern expressed over hazard to pedestrians in congested areas such as downtown and Chinatown.

The population at risk was therefore considered to be both the occupants in the buildings and the pedestrians in areas (streets, alleys, or yards) directly outside the buildings. The population inside UMBs was calculated using square footage, building uses, and probable occupancy loads obtained from DCP (most were identical to ATC-13 occupancy estimates). The population outside UMBs was calculated using lineal feet of exposure per building face (obtained from the supplementary Sanborn sweep; see Appendix 1) and population densities for various open area conditions jointly estimated by Rutherford & Chekene and DCP. Occupancies are shown in Table 6.4-3.

The fatality rates were set as follows:

1. Using gross fatalities in the Bay Area that have been previously published (Steinbrugge et al., 1972; Steinbrugge et al., 1981), the total number of fatalities ascribed to unstrengthened UMBs in San Francisco were estimated to be between 1,000 and 1,500 for the 8.3 San Andreas scenario. This number also appears to be of the right order of magnitude considering the estimated 700-800 deaths in San Francisco in 1906, and the deaths estimated for other California earthquakes that have affected significant number of UMBs (Steinbrugge, 1982; ATC, 1985).

2. Using the calculated populations at risk in the buildings and on the street, and assuming a 2.5 ratio of street death to building deaths, the ATC-13 fatality rates in the 5-45% damage states were proportioned to generate the 1,000-1,500 range of deaths for the 8.3 San Andreas event in the 5-6 pm time period. The ATC fatality rates for 80% and 100% damage were not changed.

3. The rates were further refined by running a simulation of Loma Prieta and setting deaths to greater than zero but less than 20 for the unstrengthened case.

4. It was also felt that the characteristics of Retrofit Alternative 2 would produce more damage than Retrofit Alternative 3 but without a proportional increase in casualties. Since life threatening damage cannot be differentiated from other damage in the methodology of this study, fatality rates for Alternatives 2 and 3 were adjusted to reflect that the damage in strengthened buildings is likely to be of a different type and less threatening than the damage in unstrengthened buildings, and that a given percentage of damage in Alternative 2 may be less threatening than the same percentage of damage in Alternative 3. Since the strengthening work in Alternative 1 would also change the nature of failure modes, minor adjustments were also made to these rates, consistent with the adjustments described above. Considering that fatality rates are normally estimated only to an order of magnitude of accuracy, these adjustments are considered minor and justified to better reflect probable building performance.

Fatality rates used are shown in Table 6.4-4. The large number of different rates shown in Table 6.4-4 should not be construed to imply a commensurate level of accuracy. After benchmarks and trends were established, smooth transitions were used from one rate to another, resulting in the variations shown. The rates themselves, and therefore the absolute number of deaths estimated, are thought to be accurate within a factor of 2 at the high end (large earthquake, large number of deaths) and within a factor of 4 at the low end (small earthquake, small number of deaths). However, since similar rates are applied to all Retrofit Alternatives, comparisons can be made without application of such large error factors. Hospitalized injuries were taken as four times total deaths (Steinbrugge et al., 1972; ATC, 1985).

Table 6.4-3: Occupancies for Calculation of Exposure to Fatality Rates

Building Occupancies (Occupants per 1000 Square Feet)									Occupancy For Lost Time Calculations
Occupancy	Day	Occupancy for Times Used in Fatality & Injury Calculations							
		10pm-7am	7am-9am	9am-12pm	12pm-1:30pm	1:30pm-5pm	5pm-6pm	6pm-10pm	
Residential	Weekday	3.1	1.6	1.2	1.2	1.2	1.2	3.1	3.1
	Sunday	3.1	1.6	1.6	1.6	1.6	1.6	3.1	
Office	Weekday	0.3	1	4	2	4	1	0.3	4
	Sunday	0.3	0.3	0.3	0.3	0.3	0.3	0.3	
Commercial	Weekday	0.5	2	8	10	8	6	1	4
	Sunday	0.5	0.1	2	4	6	6	1	
Industrial	Weekday	0.25	1	2.5	2.5	2.5	1	0.25	2.5
	Sunday	0.25	0.25	0.25	0.25	0.25	0.25	0.25	
Assembly	Weekday	0.25	0.5	1	2	2	3	6	2
	Sunday	0.25	2	10	10	10	4	2	

Street Occupancies (Occupants per 1000 Lineal Feet)								
Streets in Study Areas 1,7	Weekday	2	100	50	150	100	200	100
	Sunday	2	10	50	100	100	100	10
Streets in Study Areas 4,5,8	Weekday	1	60	20	70	40	120	40
	Sunday	1	10	30	30	30	30	10
Streets in Study Areas 2,3,6,9-11	Weekday	0.5	30	10	30	20	60	1
	Sunday	0.5	10	10	10	10	2	1
Other Open Space	Weekday	0	2	1	1	1	5	0
	Sunday	0	1	1	1	1	2	0

Table 6.4-4: Fatality Rates for Street and Building Occupants

Strengthening Alternative	Location	Average Damage					
		0%	5%	20%	45%	80%	100%
No Strengthening	Building	0	0.000010	0.00035	0.0035	0.035	0.2
	Street	0	0.0002	0.003	0.07	0.12	0.15
Retrofit Alternative 1	Building	0	0.000009	0.00033	0.0034	0.035	0.2
	Street	0	0.000018	0.0028	0.065	0.12	0.15
Retrofit Alternative 2	Building	0	0.000007	0.00023	0.0028	0.35	0.2
	Street	0	0.000014	0.002	0.055	0.2	0.15
Retrofit Alternative 3	Building	0	0.000008	0.0003	0.0032	0.35	0.2
	Street	0	0.000016	0.0027	0.06	0.2	0.15

6.5 LOSS OF USE OF BUILDINGS

6.5.1 GENERAL METHODOLOGY

Loss of use of buildings, or "downtime", can form a significant portion of total monetary losses from damage in an earthquake. Statistical data on downtime does not exist in the literature, although isolated anecdotal information is available, particularly related to the Loma Prieta event. ATC-13 (ATC, 1985) has loss of function related to damage (as a percentage of replacement cost) for different occupancies based on expert opinions. The ATC-13 relationships do not consider size of building nor is the concept of a critical loss level used. Critical loss level is the loss which is likely to trigger demolition or major reconstruction rather than immediate repair and reoccupancy. A critical loss level of 65% of replacement cost was recently suggested for mid-rise buildings (EERI, 1989).

Critical loss level was considered important in this study because it would yield a measure of loss of URM building stock. Loss of building use would therefore be split into that portion representing a long-term loss, and that portion presumed to be repaired as soon as possible. Buildings that are repairable could be temporarily closed due to emergency engineering evaluations, and may be partially or totally unusable while under repair. Since dollar losses per building will be available in this study, repair times can be estimated using rates based in reasonable daily expenditures by contractors.

The general damage and casualty estimates, previously discussed, have been based on averages over many buildings. There is insufficient information available on each building and insufficient historical data to consider calculations on individual buildings realistic. However, the logic proposed for use in estimating number of building demolitions and lost time is based upon probable outcomes under realistic individual building damages, not averages. For example, if the critical loss level is set at 50% of replacement cost, each building suffering over 50% damage is likely to be demolished, regardless of what the average damage is. For downtime calculations, therefore, the following procedure was used:

1. For each building, using the average damage calculated as previously explained, the likelihood of all damage states was calculated, using probability distributions suggested in ATC-13.

2. The probability that the individual building would be damaged over the critical loss level was multiplied times the building square footage and that area accumulated over all buildings as long term lost area. The number of occupants associated with this square footage was also accumulated using the appropriate occupant load (occupants living or working in the building. See Table 6.4-3)

3. The downtime associated with each damage state below the critical loss level was calculated and multiplied by its probability of occurrence to obtain a weighted downtime, in days lost, that would appropriately consider the building's likely dollar damages. The calculation of weighting factors based on the probability distribution of damage is discussed in more detail in Appendix 4.

4. The total occupants living or employed in the building as shown in Table 6.4-3, is multiplied by the days lost to obtain "occupant-days" lost.

6.5.2 LONG-TERM LOSS

Long-term loss of building use was assumed to occur in seriously damaged buildings due to outright demolition or to long delays (4-6 months) in the decision-making process which could result in either demolition or massive reconstruction. The effect to occupants is presumed to be the same for either demolition or long delay.

Critical loss levels were set at 40% replacement costs for unstrengthened buildings and 50% replacement cost for strengthened buildings. These figures represent repair costs in the $25-35 per square foot range. Forty to 50 percent damage is a lower cut-off than has been suggested for other buildings, but UMBs as a class are more likely to have other liabilities, such as inadequate fire protection, handicap access, and building service systems, which could affect an owner's decision to repair or demolish. The projected long-term loss for the simulation of Loma Prieta (254,138 sq. ft.), even using a 40% actual loss factor, may prove to be low when all long-term losses are accounted for. Such building loss data is, unfortunately, not readily available.

The higher cut-off of 50% was used for strengthened buildings on the assumption that owners who have spent money on seismic strengthening (and probably other improvements) are more likely to attempt to salvage their buildings.

The total long-term loss estimate is quite sensitive to the critical loss level chosen. For the Magnitude 8.3 San Andreas event, the loss was estimated at 12,000,000 sq. ft. using a 50% critical loss level and 18,000,000 sq. ft. using 40%. Area not included in long term loss will, of course, be accounted for in the occupant-days lost category, as damage to that area was assumed to be immediately repairable. The most representative view of the effect of damage on occupants is a combination of "occupant-days lost" and "occupants affected by long term loss". To obtain such a combined parameter, "occupants affected by long-term loss" must first be converted to the equivalent of "occupant days lost" by multiplying it by a time period to represent the effect of long-term closure or demolition; 200 to 350 days is suggested. This product can then be added to "occupant days lost" and the sum used to compare various scenarios. It should be recognized, however, that embedded in the calculation of both "occupant days lost" and "occupants affected by long-term loss" are lengthy losses of building use which would undoubtedly result in use of alternate facilities. The time period that separates building closures that directly relate to business or personal loss and closures that will result in relocation is probably highly variable. The parameters discussed therefore should be considered to be a measure of the time the affected occupants would be forced out of their original building and not directly related to business lost or the need for temporary shelter.

6.5.3 LOSSES DUE TO REPAIRS

Buildings that are damaged below the critical loss level are assumed to be repaired as soon as possible. Labor and material necessary for repair are assumed to be available without undue delays. Such shortages did not materialize after Loma Prieta but certainly may in larger events.

Moderate repair rates were used for all conditions in this study as shown in Table 6.5-1. Repair times are calculated by dividing the dollar loss (replacement value times percent loss) by the appropriate repair rate.

Table 6.5-1: Damage Repair Rates

Total Repair Cost	Repair Rate
<$50,000	$4,000 per day
$50,000 - 200,000	$8,000 per day
>$200,000	$16,000 per day

The total lost time is composed of an initial evaluation period, the length of which is dependent on the damage state, and repair period. Repair periods used for lost time are either 33% or 66% of repair times to account for partial or early occupancy within the repair time.

The algorithm used for each damage state is shown in Table 6.5-2.

Table 6.5-2: Total Days Lost in Buildings to be Repaired

Damage Ratio	Lost Days	
	Evaluation Period	Repair Period
0-10%	0	0
10-15%	5	0
15-25%	5	33% Repair Time
25-40% (unstrengthened)	20	67% Repair Time
25-50% (strengthened)	20	67% Repair Time
>40% or 50%	--	Long Term

As discussed in 6.5.1, the above algorithms are used for each damage state of each building, with the lost days thus calculated being weighted by probability of occurrence of that damage state. Finally, the days lost in each building is weighted to consider the number of occupants affected by multiplying the loss times the effective occupancy from Table 6.4-3 to obtain "occupant days lost".

6.6 LOSS ESTIMATE TABLES

Two loss tables are presented for each selected earthquake scenario and for each strengthening alternative. The earthquake scenario includes specification of fault source, magnitude and time of day. The first table in each set accumulates all damage parameters by prototype and the second by UMB Study Area. The three earthquake scenarios selected by DCP are: 1) Annual Expected Losses (probable losses from all earthquakes reported on an annual basis); 2) Magnitude 7 on Hayward Fault at 3 am, 3) Magnitude 7 on Hayward Fault at 3 PM. A fourth scenario has been included to represent the probable worst case: a Magnitude 8.3 on the San Andreas Fault at 5:30 pm. Also included is an equivalent scenario to the Loma Prieta earthquake of October 17, 1989; this scenario was calculated for the unstrengthened case only. Expected values have been estimated for each parameter and are printed in the tables as single numbers rather than ranges, for convenience and clarity. Estimated accuracies vary by parameter and are discussed in the body of the text.

The following loss parameters are included:

Property Loss (%)	Building damage as a percentage of replacement cost
Property Loss ($):	Percentage damage times area times replacement cost per square foot.
Casualties Building (#):	Number of deaths expected to occur inside UMBs.
Casualties Street (#).	Number of deaths expected to occur on the street caused by damage to UMBs.
Hospital Injuries (#)	Number of injuries requiring hospitalization. Taken as 4 times the total deaths.
Occupant Days Lost (Occ.-days).	An accumulation of the number of days of functional loss multiplied by the associated occupancy. The category only considers days lost in buildings that are assumed to be repaired. To assess total disruption to occupants, it is necessary to consider both "Occupant Days Lost" and "Long Term Loss - Occupants Affected" See Section 6.5. Calculations consider each building using a probabilistic technique that separates the square footage into various categories. The totals therefore do not represent closures of a subset of actual buildings.
Long Term Loss-Area:	The square footage that is expected to receive greater than 50% damage (40% for unstrengthened buildings) and may therefore be demolished or at least will not be immediately repaired. Calculations consider each building using a probabilistic technique that separates the square footage into various categories. The totals therefore do not represent the loss of a subset of actual buildings. An estimate of the number of buildings that might be affected by long-term loss can be obtained by dividing this area by a representative building size.
Long Term Loss-Occ Affected:	The number of occupants affected by Long Term Loss-Area. Calculated as the Long Term Loss-Area multiplied times the appropriate occupant load. To assess total disruption to occupants, it is necessary to consider both "Long Term Loss - Occupant Affected" and "Occupant-Days Lost". See Section 6.5.

Annual Expected Loss

Action No Strengthening

Prototype	Property Loss (%)	Property Loss ($)	Fatalities Building (#)	Fatalities Street (#)	Hospital Injuries (#)	Occupant Days Lost (Occ-days)	Long-Term Loss (> 40%	
							Area (sqft)	Occ. Affected (#)
A	1.2	251889.	0	1	4	476	2046	7.1
B	1.6	1648480.	2	.2	1.9	4514	16560	52.3
C	1.1	2873720.	.8	2	4.2	10531	27331.	112.1
D	2.1	5769705.	1.0	6	6.2	24619.	50841	182.0
E	2.0	795529.	.1	.1	.8	1153	10306	26.1
F	2.3	7827440.	.9	.5	5.6	23482.	100431.	256.5
G	1.5	1717300.	.2	.4	2.4	3195	11355	45.4
H	1.7	5977259.	1.2	5	6.8	18839	45544	131.7
I	1.8	1446773.	.3	.3	2.3	2474.	11550	46.5
J	2.0	7459054.	1.1	.7	7.4	33811.	58300	232.8
K	1.0	461002.	.1	.1	.9	1083.	3558.	14.6
L	1.1	1456291.	.3	.2	2.2	4397	12253.	50.2
M	1.1	1533054.	.3	.1	1.5	3563	10628	43.6
N	1.2	5487733.	1.3	.3	6.3	23631.	43658.	179.0
O	1.7	2093652.	.2	.2	1.6	2287	15494	31.0
Total	1.6	46804930.	8.1	4.5	50.7	158054.	419954.	1461.0

These data should not be reproduced or used in any way without consideration of the limitations in accuracy as discussed in Sections 6.1 thru 6.5 of this report.

Scenario San Andreas North Near S.F. Magnitude 8.3 Time 5:30 p.m.

Option No Strengthening

Prototype	Property Loss (%)	Property Loss ($)	Fatalities Building (#)	Fatalities Street (#)	Hospital Injuries (#)	Occupant Days Lost (Occ-days)	Long Term Loss Area (sqft)	Long Term Loss Occ Affected (#)
A	32.0	5661130	2.1	15.9	76.0	12537	37452	[illegible]
B	37.1	39193230	16.2	62.1	313.2	113026.	742333	[illegible]
C	36.9	93338930	11.7	56.2	271.9	328741	1432587	[illegible]
D	47.1	131304700	61.8	93.6	621.6	309869	2302508	7072.3
E	46.5	18510520.	4.3	26.0	121.4	15611.	413896.	1054.3
F	51.8	178854400.	59.3	108.3	670.7	263369	3377434	10241.5
G	34.9	40442230	13.8	66.9	322.5	66087	480480	1923.3
H	42.5	146345000	76.6	99.8	705.4	738285.	2033095	8105.5
I	45.0	35794990.	14.7	46.0	242.5	40106.	434726	1375.0
J	45.8	167374000.	66.7	98.7	661.7	452822.	2231813.	8903.2
K	28.8	12863630.	1.2	22.5	95.0	32918.	151161	550.8
L	32.9	42858540.	4.7	49.2	215.9	139907.	611257	2505.2
M	32.7	46597180.	4.2	28.9	132.6	109056	545689.	2237.2
N	37.5	175539700	19.2	71.9	364.1	734302	2330797	9602.3
O	49.8	50885490	28.2	43.1	285.5	36515.	799202	1538.4
Total	41.3	1196670000	384.8	890.1	5099.8	2993253.	13475040	54942.[illegible]

These data should not be reproduced or used in any way without consideration of the limitations in accuracy as discussed in Sections 6.1 thru 6.5 of this report.

WORKSHOP PARTICIPANTS

DAVID ABBOTT
Emergency Preparedness Coordinator
Dept of Health Services
714 P Street, Room 842 (IMS #A-22)
Sacramento, CA 94234-7320

RICHARD ANDREWS, Ph.D.
Chief Deputy Director
Office of Emergency Services
2151 East D Street, Suite 203A
Ontario, CA 91764-4452

EILEEN BAUMGARDNER
Assistant Director for Plans & Preparedness
OES Headquarters
2800 Meadowview Rd
Sacramento, CA 95832

DONALD CHEU, M.D.
OES Disaster Medical Care Committee
1200 El Camino Real
San Francisco, CA 94080

ANN H. COULSON
Dept. of Epidemiology
School of Public Health
Room #71-236
Center for Health Sciences
University of California (UCLA)
405 Hilgard Avenue
Los Angeles, CA 90024

MICHAEL DURKIN
Durkin and Associates
22955 Leonora Drive
Woodland Hills, CA 91364

PAUL FLORES, Director
Southern California Earthquake
Preparedness Project
1110 E. Green St., #300
Pasadena, CA 91106

CALVIN FREEMAN
Administrative Deputy
Emergency Medical Services Authority
1030 15th Street, Ste. 302
Sacramento, CA 95814

TERENCE HANEY
The Terence Haney Company
5943 Salamea Avenue
Woodland Hills, CA 91367

M. NEAL HARDMAN
Senior Architect
Office of Statewide Health Planning
and Development

BRUCE E. HAYNES, M.D.
3215 Trumbull St.
San Diego, CA 92106

WILLIAM HOLMES
Principal Structural Engineer
Rutherford and Chekene
303 Second St., #800
San Francisco, CA 94107

NICHOLAS JONES, Ph.D.
Dept. of Civil Engineering
John Hopkins University
3400 N. Charles St.
Baltimore, MD 21218-2699

ALEX KELTER
Chief, Emergency Preparedness
and Injury Control
Dept. of Health Services
714 P Street, Rm. 842 (IMS #A-22)
Sacramento, CA 94234-7320

GUS KOEHLER, Ph.D
Emergency Medical Services Authority
1030 15th Street, Suite 302
Sacramento, CA 95814

SHIRLEY MATTINGLY
Director of Emergency Management
City of Los Angeles
200 N. Main St., Room 300
Los Angeles, CA 90012

FRANK MCCLURE
Consulting Structural Engineer
54 Sleepy Hollow Lane
Orinda, CA 94563

WILLIAM MEDIGOVICH
Regional Director
FEMA, Region 9
Presidio of San Francisco
Building 105
San Francisco, CA 94129

WILLIAM NESBITT, M.D.
DISASTER Medical Services Consultant
P O Box 192
Fairfield, CA 94533

ERIC K. NOJI, M.D.
Division of Environmental
Hazards & Health Effects
U.S. Centers for Disease Control
Mailstop F-28
1600 Clifton Rd., N E
Atlanta, GA 30333

ROBERT A. OLSON
VSP Associates, Inc.
455 University Ave.
Suite 340
Sacramento, CA 95825

JAMES PETRONI
California Specialized Training Institute
P. O. Box 8104
San Luis Obispo, CA 93403-8104

LAWRENCE REAVELEY
Reaveley Engineers
1515 South 1100 East
Salt Lake City, UT 84105

PAUL ROTH, M.D.
Division of Emergency Medicine
School of Medicine
University of New Mexico
Albuquerque, NM 87131

JEFF RUBIN
Emergency Medical Services Authority
1030 15th Street, Suite 302
Sacramento, CA 95814

SHINOBU SAKAI
Cambridge Architectural Research, Ltd.
The Oast House, Malting Lane
Cambridge CB39HF, UK

CHARLES SAUNDERS, M.D.
Medical Director, Paramedic Division
San Francisco Health Dept.
135 Polk Street
San Francisco, CA 94102

CHARLES SCAWTHORN, Ph.D.
EQE, Inc
595 Market Street, 18th Floor
San Francisco, CA 94105

PAULA SCHULTZ
Bay Area Regional Earthquake
Preparedness Project
Metro Center
101 8th Street
Oakland, CA 94607

DANIEL SMILEY
Emergency Medical Services Authority
1030 15th Street, Suite 302
Sacramento, CA 95814

GORDON S. SMITH, M.D.
Center for Injury Prevention
School of Hygiene and Public Health
John Hopkins University
615 N. Wolfe Street
Baltimore, MD 21205

KARL V. STEINBRUGGE
Consulting Structural Engineer
6851 Cutting Blvd.
El Cerrito, CA 94530

CHARLES C. THIEL, JR., Ph.D.
Consulting Engineer
365 San Carlos
Piedmont, CA 94611

KATHLEEN TIERNEY, Ph.D.
Disaster Research Center
University of Deleware
Newark, DE 19716

ROGER TRENT
Dept. of Health Services
714 P Street, Room 842 (IMS #A-22)
Sacramento, CA 94234-7320

DONNA WESTLAKE
Emergency Medical Services Authority
1030 15th Street, Suite 302
Sacramento, CA 95814